Performance Analysis and Comparison of Journal Bearing using Ferro Fluid & Magneto-Rheological fluid by Computation Fluid Dynamics

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Abstract— Now days the works are focuses on Smart fluid technology which is an emerging field of research and that has lead to the introduction of Ferro fluids, they are smart materials whose rheological properties (viscosity, yield stress, shear modulus etc.) can be readily controlled on appliance of an magnetic field. Recent studies show that there is an increasing interest in designing hydro dynamically lubricated bearings using electro-rheological fluids (ERFs) or magneto rheological fluids (MRFs). Both smart fluids behave like Bingham fluids, and thus the Bingham plastic model is used to describe the grease and the electro-rheological (ER) and magneto-rheological (MR) fluids behavior of the non-Newtonian fluid flow. This work is concerned with the Computational fluid Dynamics of the hydrodynamic journal bearings lubricated with Ferro fluid and comparison of magneto rheological fluid. .. The solution renders the bearing performance characteristics, namely, load carrying capacity, attitude angle, frictional force at the journal surface, friction Coefficient and bearing side leakage. Ferro fluids can solve many difficult sealing, lubricating, detection, heat transfer and damping problems. Design of smart journal-bearing systems is an important issue that opens up the possibility for semi active dynamic control of bearing behavior using smart fluid technology.

Key words: Ferro fluid, magneto-rheological, fluid journal bearings, hydrodynamic analysis, comparison by computational fluid dynamics

NOMENCLATURE

c= radial clearance
D= bearing diameter
e= eccentricity
f= friction coefficient
fm= unit volume value of the induced magnetic force
h= lubricant film thickness
hm= magnetic field intensity
hmo=characteristic value of magnetic field intensity
I= strength of the current passing through the wire
J= Jacobian of transformation
Mg= magnetization of the ferrofluid
Rs= radius of inner cylinder
Ro= distance between each grid point and the bearing centre
ri= radius of outer cylinder
rw= displaced distance from the wire position to the bearing centre
Re= Reynolds number
(u,v)= velocity components in x and y- direction
(U,V)= velocity components in ξ and η-direction
V= linear velocity in the inner cylinder
(x,y)= coordinates in physical domain
Z= physical plane
ε= eccentricity ratio = e/c
ηs= the value of η on the inner cylinder
θ= angle in direction of rotation
θi= the half of the span of groove angle
μ= viscosity
μo=permeability of free space of air
ρ= density
(ξ, η)= coordinates in computational domain
ϕ= attitude angle
ψ= position angle of the displaced wire magnetic model
ω= angular velocity of the iner cylinder.

I. INTRODUCTION

Lubricant characteristics are often controlled by additives to meet specific engineering requirements. Polymer-thickened oils behave as pseudo plastic or dilatants fluids. The viscosity of these lubricants loaded with additives is not constant and usually some non-linear relation between shear stress and shear strain rate is found. This relation can often be represented by a power law. The performance characteristics of hydrodynamic bearings using non Newtonian lubricants are different from those of the same bearing with Newtonian lubricants.

Ferro fluids consist of three basic components, namely, a base fluid or carrier fluid, ferromagnetic particles and a coating on each particle. Ferro fluids are an interesting type of liquids, because they have liquid properties and act like a ferromagnetic material. Many properties of the ferrofluid are similar to those of the base fluid. Since the concentration of the magnetic particles is low, 3–10%, they do not affect the density, vapor pressure, pour point, or chemical properties of the liquid, but there is an increase of the ferrofluid viscosity compared with the viscosity of its base fluid.

Ferro fluids can solve many difficult sealing, lubricating, detection, heat transfer and damping problems. Applications of ferrofluids are usually based on their controllability by an external magnetic force.Ferro- Fluids and devices incorporating them have found applications in high-vacuum equipment, laser systems, computers, inertia dampers, loudspeakers, material separation, domain detection and many other areas.

Magneto rheological fluid (MRF) is a manageable fluid that exhibits drastic changes in rheological properties adjustable and interchangeable to the applied magnetic field strength. MRF is a kind of controllable or smart fluids whose rheological properties can be dramatically and reversibly varied by the application of an external magnetic field in a very short period of time. The MRF has the property of a normal viscosity in the absence of an external magnetic field, but in the presence of a strong magnetic field immediately solidifies to a grease state.

The following research had be done on smart fluid by different researchers like K.P. Gertzos, P.G. Nikolakopoulos, C.A. Papadopoulos [1] has shown performance characteristics and the core formation in a hydrodynamic journal bearing lubricated with a Bingham fluid were examined. The Navier–Stokes equations were solved using the FLUENT package. The results of the developed 3-D CFD model were compared with theoretical and experimental results of previous investigations, for both Newtonian and Bingham lubricants, and found to be in very good agreement. As the value of eccentricity increases, the solid on the bearing separates into two or three parts and a floating core between these parts is observed. The load carrying capacity, the film pressure, and the frictional force of a Bingham solid are larger than those of a Newtonian fluid and they increase as the yield stress T0 increases. For low of eccentricity ratios, the effect of yield stress T0 on the journal behavior is small. Therefore, semi-active control of the journal is possible by varying these quantities.

N. S. Patel, D. P. Vakharia, and G.M. Deheri3 [2] has done theoretical comparison with the conventional lubricants suggests that the nondimensional pressure and load-carrying capacity get increased while friction force and coefficient of friction get decreased. The variation of pressure distribution, load-carrying capacity, friction force, and coefficient of friction are presented. B.S.Shenoy, R.S.Pai, D.S.Rao, R. Pai [3] studied the overall EHL analysis of full journal bearing (360^o) which has been conducted using the sequential application of Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD).. The simulation results of Elasto-hydrodynamic lubrication have a good agreement with that of the standard lubrication solutions. These techniques has been successfully implemented in finding the bearing surface deformation under static load and the approach can be extended in predicting the bearing performance under dynamic loading condition. Dimitrios A. Bompos, Pantelis G. Nikolakopoulos [4] has addressed the problem of magnetorheological fluid lubricated journal bearings operating. He developed a tool for solving the coupled magnetic-rheological flow problem.For a selected number of bearing states, several L/D ratios, magnetic field variations, solutions were obtained in terms Sommerfeld number variation. The results demonstrate that, in comparison to a normal bearing (lubrication without magnetic field), the presence of magnetic field can be beneficial for the bearing characteristics such as increased load-carrying capacity, whereas the results regarding the friction coefficient lead to a less beneficial function under the influence of the magnetic field

T. P. Indulekha, M. L. Joy, K. Prabhakaran Nair [5] carried out the analysis and made following conclusions are made. 1. At any eccentricity ratio, the load carrying capacity of a plain circular bearing decreases with increase in peclet number.2. Significant reductions in load capacity are obtained at large values of eccentricity ratio and peclet number.3.The attitude angle decreases slightly with increase in pectet number at any eccentricity ratio.4. At large values of eccentricity ratio, the thermal effect produces in significant effect on the end leakage. H.S. CHANG, C.Q. CHI and P.Z. ZHAO [6] have studied on two types of four-pad step-pocket journal bearings, lubricated with ferromagnetic fluid. The ferrofluid lubrication can yield higher overall bearing performance than that obtained with ordinary fluid lubrication. (1) The viscosity is increased (2) Pressure induced by the magnetic field is much smaller (< 3%) than that obtained due to the hydrodynamic effect. In approximate calculation, this pressure can be neglected. (3) The side leakage of the ferrofluid is decreased.(4) The advantages of the four-pad step-pocket journal bearing in comparison with the plain cylindrical journal bearing are as follows: (a) low friction loss giving low temperature rise under high rotational speeds without any cooling device; (b) high boundary lubricating effect (c) low altitude angle giving high stability characteristics at high rotational speed conditions. R. Ravaud, G. Lemarquand, V. Lemarquand [7] has presented an analytical method to design ironless structures composed of ring permanent magnets and ferrofluid seals. This paper has presented a method for improving the ferrofluid seal static capacity. The ring permanent magnet height plays a key role in the optimization of the ferrofluid seal capacity. The more the ring permanent magnet heights are important compared to their radial widths, the more the magnetic potential energy in a given volume of ferrofluid seal is important. P. Kuzhir [8] has demonstrated in his study that in this approximation the magnetic field plays no role in the absence of cavitations. In the frame of the free boundary approach we arrive to the following conclusion valid for lightly loaded ferrofluid bearings with shaft eccentricity eo0.3.The magnetic field has two positives effects, reducing probability of ferrofluid leakage:1. At low speed operation or high magnetic fields (A410), magnetic field flattens lateral free boundaries of the lubricant film and, consequently, does not allow the film to overcome bearing ends. 2. At higher speed operation or low magnetic fields (0.5oAo1), the field provides a super-atmospheric pressure in the whole lubricating film that eliminate cavitation region, and, so prevent air suction into the ferrofluid film. T.A. Osman a,G.S. Nada b, Z.S. Safar b [9] in his studies showed that the bearing performance is significantly modified when the magnetic effects are comparable with the hydrodynamic effects, namely, when the bearing operates at low eccentricity ratios, the magnetic field is high, the rotation speed is low and the relative clearance is large. Improving the bearing performance characteristics can be greatly increased not only by proper selection of the magnetic field model, but also with careful choice of the design parameters of the model used. The analysis reveals that the magnetic force is able to increase the bearing load if a proper magnetic field distribution model is used. Negative gradients of the applied are necessary. The side leakage is highly decreased. It can be completely eliminated by appropriately designing the bearing geometry and the magnetic field. Little change of the attitude angle is obtained. M. Mongkolwongrojn and P. Arunmetta [10] studied on the static and dynamic characteristics of short circular bearings lubricated with non-Newtonian soybean-based oil have been investigated theoretically. It 'was found from the numerical results that the nonlinear factor has much influence on the oil film pressure, load-carrying capacity, and spring and damping coefficients of these oils. S. P. TAYAL [11] reference results the following conclusions can be drawn. (1) The values of the load support, frictional force and end leakage, for all eccentricity ratios, are less for pseudoplastic lubricants ($n < 1.0$) and greater for dilatant lubricants ($n > 1$ .O) than those for Newtonian lubricants ($n = 1.0$). (2) The values of the friction coefficient P(R/C), at all eccentricity ratios, are greater for pseudoplastic lubricants and less for dilatant lubricants than those for Newtonian lubricants. (3) The temperature rise parameter of pseudoplastic and dilatants lubricants does not show a definite pattern with respect to that of Newtonian lubricants. This may improve the dynamic behaviour of the journal bearing system when dilatant lubricants are used. T.A. Osmana,*, G.S. Nadab and Z.S. Safarb[12] has developed a modified Reynolds equation for these non-Newtonian ferrofluids. It is a more general equation, and one that is sufficiently simple to permit ready application to any magnetic field distribution model. For an axial symmetric applied field that has a gradient only in the axial direction, an increase of the flow behavior index manifests its magnetic effect and this results in:1. Increase of the load capacity.2. Decrease of the friction coefficient. S.P. Tayalt, R. Sinhasan* and D.V. Singh [13] shows the effect of this nonlinear behavior on the performance characteristics of finite-width journal bearings is investigated using the Eyring model for the shear stress and shear strain rate. The finite element method using Galerkin's technique has been used to solve the momentum equations and the continuity equation in cylindrical coordinates, representing the flow field in the clearance space of a journal bearing system using Newtonian fluids; the non-Newtonian effect is introduced by modifying the viscosity term for the model in each iteration. Jie Peng*, Ke-Qin Zhu[14] A three-dimensional flow simulation of finite-length ER journal bearings with an external electric field imposed partially along a contractive section has been presented. The influences of ER effects, caused by the applied electric field, on the journal bearing characteristics are significant and not negligible. Compared with the Newtonian lubricant case, the effects of the ER effects provide an enhancement in the load-carrying capacity, but do have little effects on the attitude angle. The quantitative effects on load-carrying capacity are more pronounced for journal bearings operating at higher values of eccentricity ratio or lower rotary speed.

II. Analysis

The coordinate system and the geometry of a journal bearing are shown in Fig. 1. The journal rotates with an angular velocity ω and is in an equilibrium position under the external vertical load W as well as the pressure of the lubricant film. The journal axis O_j is at distance e from the bearing axis O_b. The film thickness h(θ) varies from its maximum value h_o at bearing angle θ= 0 to its minimum value h_1 at θ=π.

A. Equations to be solved

For all flows, FLUENT solves conservation equations for mass and momentum. For flows involving heat transfer or compressibility, an additional equation for energy conservation is solved. For flows involving species mixing or reactions, species conservation equations are solved or, if the non-premixed combustion model is used, conservation equations for the mixture fraction and its variance are solved. Additional transport equations are also solved when the flow is turbulent. In this paper, the conservation equations for laminar flow (in an inertial, non-accelerating, reference frame) are presented.

B. Flow of Rheological Fluid

The governing equations are solved which are required to predict the flow of Electro-Rheological fluids. Also, the factors affecting the core formation in the lubricant film have been studied and the core, which is formatted in ER fluid used, is predicted

1) Governing Equations:

The viscosity of electro and magneto rheological fluids can be approximated with the Bingham law [25] as shown in Fig-1.

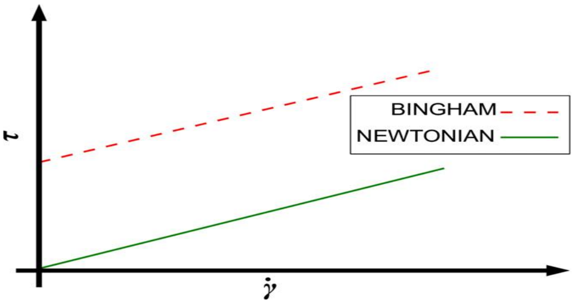

Fig-1 Bingham Model

For these types of fluid the yield stress is given by:

$$\tau = \tau_0(E) + \mu\dot{\gamma}$$

Where, τ is the shear stress of the material, τ_0 critical shear stress or yield stress and $\dot{\gamma}$ the shear rate. The relation of the critical shear stress τ_0 with the Electric field intensity E can be estimated by experimental data. For certain electro-rheological fluids this relation is available through manufacturer's literature. It is possible to obtain an equivalent or apparent viscosity:

$$\mu_a = \mu_f + \tau_0(E) \Big/ \left|\frac{\partial \bar{u}}{\partial y}\right|$$

where, μ_a is the apparent viscosity of the material and μ_f is the Newtonian viscosity of the material when the shear stress overcomes the yield stress, in which case the material is flowing. During the electrostatic simulation in ANSYS the Bingham model is defined somewhat differently by a bi-zone viscosity model as shown in Fig. 3.2. So for the purposes of the simulation the apparent viscosity is a function of two separate viscosity regions. The first region is the plastic viscosity region where the material exhibits the Bingham solid behavior. In this region the viscosity takes a high value. This is the Plastic viscosity or μ_p. When the shear stress overcomes the yield threshold, the behavior of the Bingham material is described with the viscosity of flow or μ_f.

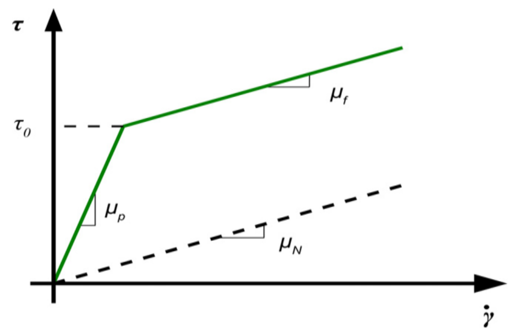

Fig. 3.2: The ANSYS bi-zone Bingham model

This work in hand is only the first step in obtaining solution to different problems in the field of electro-rheological fluid lubricated journal bearings, where the Reynolds equation has certain limitations. One of the main assumptions included in Reynolds equation is that the influence of the inertial force is omitted. Thus the use of Reynolds equation is limited when the clearance to diameter ratio becomes larger than a specific threshold. Moreover Naiver–Stokes should be more suitable for high density materials, such as the Bingham Fluids. For example, the density of typical SAE-30 oil is approximately 890 kg/m^3 whereas the MRF-132DG has a density of 2980 kg/m^3. Given the magnitude of density for the specific application, Naiver–Stokes equations have been chosen, giving a safe and generic tool for the simulation of an electro-rheological bearing

III. CONCLUSION

From review of above literature we can conclude the following points:

- The load capacity and squeeze time are more in the case of a non-uniform magnetic field than in the case of a uniform magnetic field owing to the effect of magnetization.
- The load carrying capacity, the film pressure, and the frictional force of a Bingham fluid solid are larger than those of Newtonian fluid and they increase as the yield stress T_o increase.
- The presence of magnetic field can be beneficial for the bearing characteristics such as increased load-carrying capacity in terms of the magnetic field increment, whereas the results regarding the friction coefficient lead to a less beneficial function under the influence of the magnetic field.
- The side leakage of the ferrofluid at both ends of the bearing at medium or high eccentricities can be avoided by appropriately designing the bearing geometry and magnetic field.

The objective for my PG dissertation is to study the characteristic of hydrodynamic journal bearing lubricated by ferrofluid and compare the results of it with magneto rheology fluid both by Computation Fluid Dynamics.

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